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An Aptitude-Strategy Interaction in Linear Syllogistic Reasoning

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The major goal of the present study was to demonstrate an aptitude-strategy interaction in linear syllogistic reasoning. Specifically, it was hypothesized that the efficiency of each of four alternative strategies for solving linear syllogisms--problems such as "John is taller than Bill; Bill is taller than Pete; who is tallest?"--would depend upon subjects' patterns of verbal and spatial abilities. This hypothesis was confirmed. The research also had three subsidiary goals. The first was to determine whether it is possible

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to train subjects to use various classes of strategies for solving linear syllogisms. It was found that such training is possible. The second goal was to determine whether certain strategies for solving linear syllogisms might be more efficient on the average than others. It was found that one strategy, used spontaneously by only a small minority of subjects but rather easily trainable, is more efficient than alternative strategies that subjects seem to use. The third goal was to provide a series of converging operations for testing the validity of one particular account of linear-syllogistic reasoning--a spatial-linguistic mixture model--for subjects receiving no explicit instruction in the solution of linear syllogisms. The validity of this model for the untrained subjects was upheld. It was concluded that componential analysis, a series of conceptual and methodological techniques for investigating intelligent performance, can provide a useful means for studying interactions between aptitudes and experimental treatments.

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Running head: Aptitude-Strategy Interaction

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Abstract

The major goal of the present study was to demonstrate an aptitude-strategy interaction in linear syllogistic reasoning, Specifically, it was hypothesized that the efficiency of each of four alternative strategies for solving linear syllogisms--problems such as "John is taller than Bill; Bill is taller than Pete; who is tallest?"--would depend upon subjects' patterns of verbal and spatial abilities. This hypothesis was confirmed. The research also had three subsidiary goals. The first was to determine whether it is possible to train subjects to use various classes of strategies for solving linear syllogisms. It was found that such training is possible. The second goal was to determine whether certain strategies for solving linear syllogisms might be more efficient on the average than others. It was found that one strategy, used spontaneously by only a small minority of subjects but rather easily trainable, is more efficient than alternative strategies that subjects seem to use. The third goal was to provide a series of converging operations for testing the validity of one particular account of linear-syllogistic reasoning--a spatial-linguistic mixture model--for subjects receiving no explicit instruction in the solution of linear syllogisms. The validity of this model for the untrained subjects was upheld. It was concluded that componential analysis, a series of conceptual and methodological techniques for investigating intelligent performance, can provide a useful means for studying interactions between aptitudes and experimental treatments.

An Aptitude-Strategy Interaction in Linear Syllogistic Reasoning

During the 1970's, psychologists have witnessed a belated and long overdue response to Cronbach's (1957) plea for a unification of the two disciplines of scientific psychology (see, for example, Resnick, 1976). Two responses to this plea that have received particularly widespread attention are the study of aptitude-treatment interactions (see Cronbach & Snow, 1977) and cognitive-process analysis (see Sternberg, 1977b). The present research represents a first attempt to apply a form of cognitive-process analysis, componential analysis (Sternberg, 1977b, 1978a, 1978b, 1978c, 1979), to the investigation of a particular kind of aptitude-treatment interaction, one involving the interaction between aptitude and optimal strategy during problem solving. This integration of methodologies was motivated in large part by the hypothesis that the failure to obtain reliable and replicable aptitude-treatment interactions in much previous research has been due in large part to the failure to apply certain theoretical and methodological tools that might have permitted the discovery of such interactions.

The major goal of the present study was to demonstrate an aptitude-strategy interaction in linear syllogistic reasoning. Specifically, it was hypothesized that the efficiency of each of four alternative strategies for solving linear syllogisms--problems such as "John is taller than Bill; Bill is taller than Pete; who is tallest?"--would depend upon subjects' patterns of verbal and spatial abilities. The research also had three subsidiary goals: first, to determine whether it is possible to train subjects to use various classes of strategies for solving linear syllogisms (and ideally, the class of strategy most suited to an individual subject's pattern of abilities); second, to determine whether certain strategies for solving linear syllogisms might be more efficient on the average than others; and third, to provide a series of converging operations for testing the validity of one particular account of linear-syllogistic reasoning (Sternberg, in press-a, in press-b; Sternberg, Guyote, & Turner, in press) as a model of strategy for subjects receiving no explicit instruction on how to solve linear-syllogism problems.

Interactions between aptitudes and optimum strategies for problem solution have appeared only infrequently in the psychological literature, but at least some of the interactions that have been demonstrated have been striking. Such interactions have been demonstrated in the solution of anagrams and in the solution of sentence-picture comparisons.

Gavurin (1967) randomly divided 27 college students into two groups. Subjects in one group solved anagrams under standard conditions: The experimenter presented the subjects with sets of scrambled words, and required the subjects to rearrange the letters mentally until they produced an acceptable English word. Subjects in the second group solved the anagrams under a nonstandard condition: The experimenter presented the subjects with the individual letters of each word written on individual tiles that could be manipulated manually. Gavurin hypothesized that because performance in the first condition required mental manipulation and visualization of the letters and various letter patterns, a significant correlation would be found between scores on the anagrams task and scores on a test of spatial ability; he also hypothesized that because performance in the second condition permitted manual manipulation and physical rearrangement of the letters and various letter patterns, the correlation between anagram performance and spatial test scores would be trivial. These hypotheses were confirmed. The correlation between anagrams solved and scores on the Minnesota Paper Form Board, a standard test of spatial ability, were .54 in the first condition, and -.18 in the second condition. These two correlations differed significantly from each other.

MacLeod, Hunt, and Mathews (1978) discovered pronounced individual differences in strategies for solving sentence-picture comparison problems. In a typical problem of this type, a subject is presented with a sentence, such as "The star is above the plus," and a picture, such as "$\stackrel{*}{+}$." The subject's task is to indicate whether the picture correctly depicts the content of the statement. The authors found that of 70 university undergraduates, a majority adopted a linguistic strategy well described by a model of task performance proposed by Carpenter and Just (1975). The authors also found, however, that a smaller number of subjects used a pictorial-spatial strategy. Moreover, subjects using the pictorial-spatial strategy were substantially superior in spatial ability to subjects using the linguistic strategy. The evidence suggested, therefore, that a subject's choice of strategy was dictated at least in part by his or her pattern of verbal and spatial abilities.

Previous research on the linear-syllogisms task has tended to concentrate upon identifying the strategy or strategies subjects use, and the mental representations upon which these strategies act, when the subjects solve linear syllogisms (e.g., Clark, 1969a, 1969b; DeSoto, London, & Handel, 1965; Huttenlocher, 1968; Huttenlocher & Higgins, 1971; Sternberg, in press-a, in press-b). Four basic models have been proposed. These are summarized here. The first three of the models are described in some detail in Sternberg (in press-b).

According to a spatial model (DeSoto et al., 1965; Huttenlocher, 1968; Huttenlocher & Higgins, 1971), information from the two premises of a linear syllogism is integrated and then represented in a spatial array. In the example presented earlier, the three terms in the linear syllogism would be represented in an array such as

John
Bill.
Pete

The exact form of the array will depend upon the premise adjective. Certain adjectives, such as <u>taller</u>, are more likely to lead to vertical arrays, whereas other adjectives, such as <u>faster</u>, are more likely to lead to horizontal arrays. But an array is always formed, and when the subject is asked, say, who is tallest,the subject answers the question by searching for the top member of the particular array.

According to a linguistic model (Clark, 1969b), information from the two premises of a linear syllogism is not integrated, and is represented by deep-structural linguistic propositions. In the example presented earlier, the two premises would be represented as (John is tall+; Bill is tall); (Bill is tall+; Pete is tall). When the subject is asked who is tallest, the subject searches for the item representing an individual who is tall+ relative to both other individuals.

According to a mixed model (Sternberg, in press-b), information from the two premises of a linear syllogism is first decoded into a linguistic format and then recoded into a spatial format. When the subject is asked who is tallest, he or she always scans the spatial array for the correct answer, and in certain cases, confirms the result of this scan by checking the linguistic propositions. This model attempts to capture some of the best features of the spatial and linguistic models, and also contains features found in neither of the previous models.

According to an algorithmic model (Quinton & Fellows, 1975), a surface-structural linguistic representation of premise information is sufficient to solve linear syllogisms, and can be used by subjects to bypass the more sophisticated representations proposed by the models described above. When the subject is asked who is tallest, a simple set of rules (an algorithm), described later in the article, is used to answer the question.

Two other models have been proposed that posit strategy changes over time. These models both argue that the spatial and linguistic models are each used at different levels of practice with linear syllogisms, but they disagree as to the priority of usage. According to a spatial-linguistic strategy-change model (Johnson-Laird, 1972; Wood, Shotter, & Godden, 1974), subjects first use a spatial strategy, and after practice, switch to a linguistic strategy. According to a linguistic-spatial strategy-change model (Shaver, Pierson, & Lang, 1974), subjects first use a linguistic strategy, and after practice, switch to a spatial strategy.

The present research utilized the models of linear syllogistic reasoning described above as the theoretical basis for accomplishing the goals set out earlier. Subjects in the experiment were divided into three groups. In a first group, subjects received no special training in the solution of linear syllogisms; they were required to devise their own strategies. In a second group, subjects received visualization training; they were given instruction in how to form spatial arrays and were told to use such arrays in their solution of the problems. In a third group, subjects received algorithmic training; they were shown how to use the algorithm proposed by Quinton and Fellows (1975) to solve linear syllogisms, and were told to use this algorithm. Data analyses were planned to compare the performance of the three groups.

Method

Subjects

Subjects in the experiment were 144 Yale undergraduate and graduate students, approximately equally divided between sexes. Subjects were assigned to three instructional groups at random, with the constraint that there be equal numbers of subjects in each group. All subjects were paid $2.50 per hour for their participation, which lasted about two hours.

Materials

Experimental stimuli. Experimental stimuli were three-term series problems (linear syllogisms) and two-term series problems. Typical three- and two-term series problems were "John is taller than Bill; Bill is taller than Pete; Who is tallest? John, Bill, Pete" and "Bill is not as tall as John; Who is shortest?" Bill, John." The 32 types of three-term series problems varied dichotomously along five dimensions: (a) whether the first premise adjective was marked (e.g., shorter) or unmarked (e.g., taller);[1] (b) whether the second premise adjective was marked or unmarked; (c) whether the question adjective was marked or unmarked; (d) whether the premises were affirmative or negative; (e) whether the correct answer to the question was in the first or second premise. The 8 types of two-term series problems varied dichotomously along three dimensions: (a) whether the premise adjective was marked or unmarked; (b) whether the question adjective was marked or unmarked; (c) whether the premise was affirmative or negative. There were three replications of each item type, one using the adjective pair taller-shorter, one using the adjective pair better-worse, and one using the adjective pair faster-slower.

Mental ability tests. Four tests of mental abilities were administered: two tests of verbal ability and two tests of spatial ability. The verbal tests were a word grouping task, in which subjects had to indicate which of five words did not belong with the other four, and Form S of the DAT Verbal Reasoning Test, which required subjects to solve verbal analogies with the first and last terms missing. The spatial tests were Card Rotation, from the French Kit of Reference Tests for Cognitive Factors, which required subjects to rotate two-dimensional shapes mentally and decide whether or not they were mirror images of other shapes, and Form S of the DAT Spatial Relations Test, which required subjects to visualize what forms would look like when folded up in three dimensions.

Apparatus

Experimental stimuli were presented via a Gerbrands two-field tachistoscope with an attached millisecond clock. Mental ability tests were administered in paper-and-pencil format.

Design

The main dependent variable was solution latency for each of the two- and three-term series problem types. The main independent variables in the experimental design were instructional treatment and stimulus type. There were a total of 40 different stimulus types (two- and three-term series problems) administered in three replications, and these served as the basis for the mathematical modeling used to identify strategies followed in each of the three instructional groups.

Procedure

Testing was done in one sitting, although the presentation of experimental stimuli was divided into three parts, which will be referred to as "sessions." Each session consisted of presentation of the 40 item types with one of the three adjective pairs. Mental ability testing was done at the end of the sitting, with tests presented in random order under the constraint that two tests of the same type (verbal or spatial) were never presented consecutively.

Subjects in all three groups were first told that they would be solving "relational inference" problems, and were then shown three typical relational inference items. Next, subjects were instructed in how to solve the problems, as described below. Then, subjects in all groups were told that "accuracy is extremely important. Though you should attempt to solve each problem as rapidly as you are able, it is most important that you make the fewest errors possible."

Subjects in all groups were told that their task was to "read the statement(s), answer the question based on your understanding of the statements(s), and choose one of the answer choices" by pressing the appropriate button on a button panel. Subjects in the visualization and algorithm groups were further told that "though there are many methods of solving these problems, for the purposes of this experiment, you will be asked to solve these problems using the following method." The "following method" differed across the two instructional groups.

Members of the visualization group were told to "try to organize the statements into a spatial array or a series formation. Try to visualize the relationships described in the statements." Subjects were then shown examples of different pictorial arrays that might correspond to what they would construct in their heads. They were told that they could use any of the pictorial formats, or some other, so long as they used some pictorial format.

Members of the algorithm group were told to read the final question first, then to read the first statement, then to answer the question in terms of the first statement, and finally to scan the second statement. "If the answer to the first statement is not contained in the second statement, the answer to the first statement is the correct response to the entire problem....If the answer to the first statement is contained in the second statement, then the other answer choice in the second statement is the correct response to the entire problem." As subjects went through the steps, they followed along an actual example of the method applied to a sample linear syllogism.[2]

Following the instructions, subjects were given ten practice items before starting the actual test items.

Results

Original Groups

Group means. Table 1 shows mean latencies for subjects in each of the three groups. The data of main interest are for the three-term series

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Insert Table 1 about here

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problems averaged over sessions. Means are also shown for the three-term series problems for each individual session, and for the two- and three-term series problems combined.

The question of interest was whether there would be any effect of training condition. A one-way analysis of variance on the three-term series latencies averaged over sessions reveals that there was a highly significant effect of condition, $F(2,141) = 25.91$, $p < .001$. A follow-up of this analysis using the Newman-Keuls procedure indicates that the mean for the algorithmic condition differs significantly from the means for each of the other two conditions, but that the means for these two conditions do not differ significantly from each other. These data indicate that algorithmic training reduces response times relative to no training or visualization training. Visualization training, however, has no effect upon response times relative to no training at all.

Intercorrelations and reliabilities. Table 2 shows intercorrelations between and reliabilities of the solution latencies for the linear-syllogism problems. Whereas correlations between latencies for the algorithmic group and each of the other two groups are clearly below the reliabilities of the data, the correlation between the latencies of the untrained and visualization groups is at the same level as the reliabilities of the data. The high corre-

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Insert Table 2 about here

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lation between data sets, combined with the nonsignificant difference between means, strongly suggests that subjects in the visualization group are solving the linear syllogisms in the same way that subjects in the untrained group are solving the problems. Moreover, these results suggest that untrained subjects do, in fact, rely upon spatial visualization at some point during the solution process. The results are consistent with either the spatial or mixed model for untrained subjects, but not with either of the linguistic or algorithmic models, neither of which posits any spatial representation of premise terms.

Mathematical modeling. Mathematical models quantifying each of the information-processing models were fit to the latency data for both the group and individual data. Details concerning the quantification procedures, which require a somewhat lengthy exposition, are contained elsewhere (Sternberg, in press-b). The basic procedure, which has been used for other kinds of problems as well (cf. Sternberg, 1977a, 1977b, 1979; Sternberg, Guyote, & Turner, in press), involves assigning a mathematical parameter to represent the duration of each information-processing component in each model. Values of parameters are then estimated by a multiple regression of solution latencies on the independent variables (sources of problem difficulty) stipulated by each model. The models are then compared in their relative abilities to predict the solution latencies for the various item types. The total number of data points to be predicted equals the number of item types: 32 for three-term series problems, and 40 for two- and three-term series problems combined.

Fits of models are assessed in terms of two indices of model quality, R^2 and root-mean-square deviation (RMSD). The first index, R^2, is a measure of the proportion of variance in the response-time data accounted for by the set of independent variables specified by a given model; higher values, of course, are indicative of better fit. The second index, RMSD, is a measure of the root-mean-square deviation of the observed values from the values predicted under a given model; lower values are indicative of better fit. Values of RMSD are expressed in the same unit of measurement as the data, so that it is possible to compare the two sets of values to each other directly. Values of R^2 and RMSD generally lead to consistent conclusions, although they need not do so if the variances of the predicted values differ across models. R^2 is sensitive to these variance differences, whereas RMSD is not.

Table 3 shows fits of the mathematical models to the latency data for each of the three groups. Fits of primary interest are those for three-

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Insert Table 3 about here

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term series problems averaged over sessions, although fits are also shown for the individual sessions, and for the two- and three-term series problems combined. We shall consider separately the fits for each of the three groups.

The results of the present experiment for the untrained group corroborate those of Sternberg (in press-a, in press-b) in supporting the mixed model over the linguistic and spatial models. The algorithmic model was not tested in either of the previous studies, although the mixed model is superior to this model as well in the present study. The levels of fit for the mixed model (and for the alternative models) are quite close to those in the previous experiments, suggesting that subjects in the untrained group probably solved the problems in much the same way as did subjects in the earlier experiments.

As might be expected from the analyses of means and intercorrelations, the results for the visualization group closely parallel those for the untrained group. Recall that although subjects in this group were trained to use a particular representation, they were not trained to use a particular set of operations to act upon this representation. Thus, either of the spatial or mixed strategies would have been consistent with the training subjects received. Again, the superiority of the mixed model held over sessions, and for the combined data of two- and three-term series problems as well.

Finally, consider the model fits for the algorithmic group. Here, the results are equivocal. The fit of the mixed model is clearly worse than in either of the other two groups, and the fit of the algorithmic model is clearly better. But the data do not distinguish these two models from each other, nor even distinguish them from the linguistic model. There are at least two reasons why this might be so, and both of them are likely to apply to some extent. First, what subjects are actually doing in the algorithmic group might be different from what they are doing in the other two groups, but might not correspond exactly to what any of the prespecified models claim the subjects are doing. This hypothesis is almost certainly correct, since the value of R^2 for the three-term series problems is considerably lower than the reliability of the data. Second, there may be in this group (and in the other instructed group as well) subjects who are using a model other than the assigned one, in this case, the algorithmic one. The failure of these subjects to follow instructions would result in a mixture of strategies within as well as between groups. This possibility will be tested later.

None of the three conditions showed evidence of an interaction between the optimum model of performance and amount of practice. There is thus no evidence to support the strategy-change models noted earlier.

<u>Correlations between solution latencies and ability factor scores</u>. A factor analysis was performed on the four mental ability tests using a principal-factor solution rotated to a varimax criterion. Two factors emerged (with

eigenvalues greater than one), accounting for % of the variance in the data. The factors could be clearly labeled as a verbal factor and a spatial factor. Since correlations with the factor scores present a good summary of correlations with the individual tests, only correlations with the factor scores will be presented here. These correlations with factor scores (estimated by regression) are presented in Table 4.

Insert Table 4 about here

The correlations indicate that the experimental stimuli provide good measures of both verbal and spatial abilities in the uninstructed and visually instructed groups. This is the pattern one would expect if subjects were using a mixture model in which both linguistic and spatial representations are used at varying points during the solution sequence. These correlations, then, are supportive of a mixed model. Correlations in the algorithmic group are generally lower than in either of the other two groups, although they are also generally significant. Since the factors are orthogonal, the significant correlations with both abilities cannot be due to any overlap in the two kinds of abilities. The data therefore suggest a mixture of representations in the algorithmic group as well, although it is not necessarily the case that the linguistic and spatial representations used in this group are the same as in the other groups. The differences in patterns of results throughout the experiment, in fact, suggest that they may well be different.

A troubling feature of these data and the previous ones is the possibility of subjects in particular groups who, for one reason or another, did not follow the instructions given to them. Although the present groupings are the optimum ones for discovering the effects of training, they may be less than optimal for discovering various properties of group data collected from subjects using a single model, whichever model that may be. In order to investigate these latter kinds of properties, subjects were regrouped in a way that would greatly increase the probability of a homogeneous strategy within each grouping.

New Groups

Composition of new groups in terms of old groups. Table 5 shows the composition of the new groups in terms of the memberships of the old groups. Subjects were assigned to new groups on the basis of individual modeling of their latency data for the linear syllogisms: Each subject was placed in a group corresponding to the strategy for which his or her individual R^2 was highest. Results of assignment by RMSD were almost identical, and had no consequences for interpretation of any results.

Insert Table 5 about here

It can be seen that each original group had at least some subjects best fit by each of the models. The proportions were rather different for the untrained and visualization groups on the one hand, and the algorithmic group on the other. A full 83% of the subjects in the untrained and visualization groups were best fit by the mixed model. These results are reassuring in that they indicate that the group data fairly represent the individual data. Although there are some individual differences, a large majority of subjects in the untrained and visualization groups do indeed use the mixed model. In the algorithmic group, just under half of the subjects were best fit by each of the algorithmic and mixed models. A smattering of subjects were best fit by each of the other two models. These data are also quite consistent with the group data, although the linguistic model does not fare as well at the individual level as at the group level. The data suggest that although algorithmic training greatly increased the number of subjects using the algorithmic model, it was by no means successful in inducing all subjects to use the algorithmic model.

Group means. Group means for each of the new groups are shown in Table 6.

Insert Table 6 about here

A one-way analysis of variance was conducted on the four group means for the three-term series problems averaged over sessions. These means differed significantly from each other, $F(3,140) = 2.76$, $p < .05$. None of the Newman-Keuls follow-ups were significant, however.

Reliabilities. Reliabilities of the three-term series latencies were quite variable, perhaps in part because of the widely varying numbers of subjects in the different groups. The reliabilities were .96 for the mixed group, .69 for the linguistic group, .78 for the spatial group, and .84 for the algorithmic group.

Mathematical models. The mathematical models were refit to the group data for each of the new groups, as shown in Table 7. Since each individual

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Insert Table 7 about here

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subject was best fit by the model designating the group identification, the expectation was that the group data for each new group would be best fit by the model best fitting each of the individual subjects. This was not always the case, however. In the linguistic group, the mixed model provided a better fit to the group data than did the linguistic model. This result is presumably due to high variability of individual parameter estimates for the linguistic model, resulting in greater difficulty for the linguistic model than for the mixed model in fitting the averaged data.

Correlations between solution latencies and ability factor scores. Table 8 shows correlations between solution latencies and ability factor scores for subjects in each of the new groups. The patterns are rather striking, and in-

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Insert Table 8 about here

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dicate a pronounced aptitude-strategy interaction in the solution of the series problems. Latencies in the mixed group were significantly correlated with both verbal and spatial factor scores, as would be expected from the nature of the mixed model, which requires formation of both linguistic and spatial representations. Latencies in the linguistic group were significantly correlated with verbal ability scores, but not with spatial ability scores. Latencies in the spatial group, however, were uncorrelated with verbal ability scores. but were significantly correlated with spatial ability scores. Finally, latencies in the algorithmic group were significantly (but weakly) correlated with verbal ability scores, but only marginally correlated with spatial ability scores. The reduced correlations with the verbal ability scores are consistent with a model in which superficial verbal processing, possibly only at the surface-structural level, is required.

These correlations are of interest from an additional point of view. For the mixed model, they confirm previous correlational findings that suggested the use of both linguistic and spatial representations in the solution of linear syllogisms. For the other models, however, they provide the first external validating evidence that the representations that proponents of the models claim subjects use when solving series problems by those models are actually used by subjects in solving the problems. In the past, arguments of this kind were made on the basis of patterns in response times. Although these patterns were potentially helpful in deciding upon real-time processes used by subjects, it has never been clear that they argued persuasively in favor of one or another representation. For example, the fact that response times show a pattern indicative of a marking operation does not argue in favor of one kind of representation or another in the execution of that operation. As it happens, the linguistic model claims the operation acts upon a linguistic representation; the spatial model claims the operation acts upon a spatial representation; and the mixed model claims the operation acts upon both kinds of representations. The present data suggest that the kind of representation used is consistent with the claims of each model for those subjects using the given model.

Discussion

The research described above accomplished its major goal—to demonstrate an aptitude-strategy interaction in linear syllogistic reasoning whereby different strategies for solving linear syllogisms draw upon different abilities. The optimum strategy for solving linear syllogisms depends upon one's pattern of abilities. The research also accomplished three subsidiary goals. First, it demonstrated that it is possible to train subjects either to use a visual representation for premise information or an algorithmic strategy for solution. In the former case, a large majority of subjects use a visual representation spontaneously, so there is little need for training. Not all of the subjects adhered to the instructions they received, and further training might be necessary to increase the proportions of subjects benefiting from the instruction presented them. Second, it was found that one particular strategy is more efficient on the average than alternative strategies for solving linear syllogisms. In particular, the algorithmic strategy (Quinton & Fellows, 1975) results in response times significantly lower than those obtained under any of the alternative strategies considered in this investigation. Third, the validity of the mixed model was again upheld for the large majority of untrained subjects.

By correlating parameter estimates for individual subjects with ability factor scores, it is possible to localize the components of information processing that are responsible for the various correlations of global task scores with the ability scores. Since the individual components of information processing under each model were not described in this article, these correlations are relegated to an appendix.

The present research has applied the methodology of componential analysis (Sternberg, 1977b, 1978a, 1978b, 1978c, 1979) to the investigation of an aptitude-strategy interaction in linear-syllogistic reasoning. In this application, a number of other issues have been dealt with as well. The strength of the interaction suggests the possibility that previous research in the aptitude-treatment domain may have failed to elicit interactions because of the use of less powerful theoretical and methodological techniques. Componential analysis seems to hold some promise as an analytic tool in future investigations of aptitude-treatment interactions.

Appendix

Correlations were computed between parameter estimates for individual subjects and factor scores for verbal and spatial abilities. These correlations are presented in Table A.

Insert Table A about here

Correlations were computed in two different ways. First, they were computed using all parameter estimates that were positive (that is, greater than zero). It was assumed that negative and zero parameter estimates of component duration represented error of measurement, and hence such estimates were treated as missing data. Second, the correlations were computed using only parameter estimates significantly positive at the .05 level of significance. Other estimates were treated as missing data. This stricter criterion for inclusion increases the probability that each estimate included in the correlational analysis is psychologically (as well as statistically) meaningful. This dual correlational procedure was previously employed by Sternberg (in press-b).

According to the mixed model, encoding and marking should be correlated with both verbal and spatial scores; negation, pivot search, and response search should be correlated with spatial scores; and noncongruence should be correlated with verbal scores. In fact, the data came close to showing just these patterns. Only negation failed to behave as predicted. According to the linguistic model, all parameter estimates should be correlated with verbal scores, and none with spatial scores. Marking, negation, and noncongruence were in fact correlated with verbal scores (for the first set of correlations), although marking was correlated with spatial scores as well. Encoding and pivot search were not significantly correlated with either kind of factor score.

According to the spatial model, each parameter should be correlated with spatial scores; encoding may also be correlated with verbal scores. In fact, both marking and pivot search were correlated with the spatial scores (for the first set of correlations). The other parameters were not correlated with either factor score. Predictions for the algorithmic model are less clear, although to the extent any correlations are obtained at all, one would probably expect them to be with verbal rather than spatial scores. Since only surface-structural properties of the premises are used, however, even the correlations with verbal tests might be expected to be weak. Only marking was correlated with any of the scores, and it was correlated with both abilities (in the first set of correlations).

Given the unreliability of individual parameter estimates, these correlations are viewed as generally supportive of the models for which they were computed. Only two significant correlations were obtained that were contrary to model predictions. Both of these were for marking. The nonsignificant correlations, of course, might be due to error in the predictions of the models, or to unreliability of parameter estimates for individual subjects.

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Footnotes

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[1]The unmarked form of an adjective is the positive form, usually used to name the scale (e.g., <u>taller</u>, <u>better</u>, <u>faster</u>); the marked for is the negative form, usually used in a contrastive sense (e.g., <u>shorter</u>, <u>worse</u>, <u>slower</u>).

[2]This strategy works for any linear syllogism that is completely determinate with respect to the placement of each term in the array. It does not work for so-called "indeterminate" linear syllogisms, e.g., "John is taller than Pete. John is taller than Bill. Who is tallest (shortest)? John, Bill, Pete." No indeterminate problems were used in this experiment, and the inability of the strategy to yield a correct answer to such problems was not mentioned.

[3] Mean error rates were 1.7% in the untrained group, 2.0% in the visually trained group, and 3.5% in the algorithmic group. The greater speed of the algorithmically-trained subjects was thus bought at the expense of some accuracy.

Table 1

Mean Solution Latencies:

Original Groups

	Untrained	Visualization	Algorithmic
3-Term Series	7.03	7.18	4.51
Session 1	7.45	7.58	4.90
Session 2	6.81	7.09	4.38
Session 3	6.84	6.89	4.28
2- & 3-Term Series	6.30	6.46	4.19

Note: Latencies are expressed in seconds.

Table 2

Intercorrelations between and Reliabilities of Solution Latencies for Linear Syllogisms

	Untrained	Visualization	Algorithmic	Reliability[a]
Untrained	1.00	.94	.81	.91
Visualization		1.00	.79	.92
Algorithmic			1.00	.91

Note: Correlations are across 32 item types.

[a]Reliability is of the internal-consistency type (coefficient alpha).

Table 3

Fits of Models to Latency Data:

Original Groups

	Mixed Model R^2	Mixed Model RMSD	Linguistic Model R^2	Linguistic Model RMSD	Spatial Model R^2	Spatial Model RMSD	Algorithmic Model R^2	Algorithmic Model RMSD
Untrained								
3-Term Series	.82	.46	.64	.56	.66	.55	.59	.61
Session 1	.75	.46	.55	.61	.53	.62	.48	.66
Session 2	.75	.41	.61	.51	.60	.52	.58	.53
Session 3	.65	.50	.57	.55	.61	.53	.58	.55
2- & 3-Term Series	.95	.44	.91	.52	.92	.51	.90	.56
Visualization								
3-Term Series	.81	.50	.65	.67	.65	.67	.53	.77
Session 1	.80	.45	.67	.57	.71	.54	.56	.66
Session 2	.79	.43	.62	.58	.57	.61	.47	.68
Session 3	.79	.40	.61	.55	.59	.56	.54	.60
2- & 3-Term Series	.93	.48	.88	.62	.89	.61	.85	.71
Algorithmic								
3-Term Series	.73	.22	.73	.22	.54	.28	.72	.22
Session 1	.66	.24	.66	.24	.51	.29	.69	.23
Session 2	.63	.22	.62	.22	.40	.28	.66	.21
Session 3	.64	.21	.63	.22	.49	.26	.67	.21
2- & 3-Term Series	.93	.21	.93	.21	.87	.28	.87	.28

Table 4

Correlations between Solution Latencies and Ability Factor Scores:

Task Scores for Original Groups

	Verbal	Spatial
Uninstructed Group		
3-Term Series	-.47***	-.43***
Session 1	-.47***	-.45***
Session 2	-.48***	-.46***
Session 3	-.40**	-.34**
2- & 3-Term Series	-.47***	-.44***
Visualization Group		
3-Term Series	-.49***	-.30*
Session 1	-.48***	-.36**
Session 2	-.54***	-.27*
Session 3	-.40**	-.25*
2- & 3-Term Series	-.50***	-.29*
Algorithmic Group		
3-Term Series	-.38**	-.30*
Session 1	-.36**	-.38**
Session 2	-.33*	-.28*
Session 3	-.41**	-.20
2- & 3-Term Series	-.41**	-.30*

*p <.05

**p <.01

***p <.001

Table 5

Numbers of Subjects in Each of Original Groups

Resorted into Each of New Groups

		Mixed	Linguistic	Spatial	Algorithmic	TOTAL
Original Group	Untrained	30	7	5	6	48
	Visualization	30	7	6	5	48
	Algorithmic	22	1	4	21	48
	TOTAL	82	15	15	32	144

Table 6

Mean Solution Latencies:

New Groups

	Mixed	Linguistic	Spatial	Algorithmic
3-Term Series	6.30	7.09	6.94	5.36
Session 1	6.76	7.47	7.24	5.66
Session 2	6.10	6.99	6.79	5.30
Session 3	6.06	6.74	6.79	5.14
2- & 3-Term Series	5.69	6.37	6.26	4.91

Note: Latencies are expressed in seconds.

Table 7

Fits of Models to Latency Data:
New Groups

	Mixed Model R^2	Mixed Model RMSD	Linguistic Model R^2	Linguistic Model RMSD	Spatial Model R^2	Spatial Model RMSD	Algorithmic Model R^2	Algorithmic Model RMSD
Mixed Group								
3-Term Series	.88	.26	.63	.45	.60	.47	.57	.48
Session 1	.87		.66		.63		.59	
Session 2	.83		.60		.52		.54	
Session 3	.81		.60		.55		.58	
2- & 3-Term	.96	.26	.91	.42	.90	.44	.90	.45
Linguistic Group								
3-Term Series	.74	.47	.68	.53	.67	.54	.54	.63
Session 1	.65		.58		.56		.50	
Session 2	.58		.55		.53		.41	
Session 3	.50		.40		.44		.31	
2- & 3-Term	.92	.47	.91	.51	.90	.52	.87	.60
Spatial Group								
3-Term Series	.60	.89	.53	.58	.68	.48	.36	.68
Session 1	.48		.38		.47		.25	
Session 2	.45		.42		.53		.32	
Session 3	.49		.46		.56		.34	
2- & 3-Term	.88	.53	.87	.56	.91	.47	.84	.62
Algorithmic Group								
3-Term Series	.63	.32	.62	.33	.56	.35	.74	.27
Session 1	.50		.50		.46		.58	
Session 2	.52		.50		.43		.65	
Session 3	.55		.53		.48		.60	
2- & 3-Term	.92	.30	.91	.31	.89	.54	.94	.25

Table 8

Correlations between Solution Latencies and Ability Factor Scores:
Task Scores for New Groups

	Verbal	Spatial
Mixed Model Group		
3-Term Series	-.45***	-.27**
Session 1	-.43***	-.32**
Session 2	-.44***	-.25**
Session 3	-.37***	-.17
2- & 3-Term Series	-.47***	-.27**
Linguistic Model Group		
3-Term Series	-.76***	-.28
Session 1	-.79***	-.30
Session 2	-.75***	-.29
Session 3	-.70**	-.23
2- & 3-Term Series	-.76***	-.29
Spatial Model Group		
3-Term Series	-.08	-.61**
Session 1	-.16	-.62**
Session 2	-.29	-.60**
Session 3	-.15	-.71**
2- & 3-Term Series	-.08	-.60**
Algorithmic Model Group		
3-Term Series	-.32*	-.28
Session 1	-.30*	-.31*
Session 2	-.29*	-.31*
Session 3	-.33*	-.19
2- & 3-Term Series	-.33*	-.28

*p <.05
**p <.01
***p <.001

Table A

Correlations between Solution Latencies and Ability Factor Scores:
Component Scores for New Groups

	Positive Scores		Significant Scores[a]	
	Verbal	Spatial	Verbal	Spatial
Mixed Model Group				
Encoding	-.27**	-.20*	-.29**	-.26**
Marking	-.24*	-.30**	-.49**	-.44*
Negation	-.20	-.11	-.10	.07
Pivot Search (Mixed)	.01	-.26*	-.26	-.39*
Response Search	-.20	-.22*	.03	-.45**
Noncongruence	-.21*	-.09	-.64**	-.04
Linguistic Model Group				
Encoding	.05	.04	.05	.04
Marking	-.72**	-.36*	-.60	.03
Negation	-.71**	-.12	-.18	-.26
Pivot Search (Linguistic)	.13	-.60	.59	-.63
Noncongruence	-.73**	-.29	-.93*	-.51
Spatial Model Group				
Encoding	-.19	-.38	-.25	-.42
Marking	-.17	-.44*	----	----
Negation	.00	.00	-.02	-.61
Pivot Search (Spatial)	-.04	-.71**	-.05	-.75**
Seriation	-.09	-.30	----	----
Algorithmic Model Group				
Encoding	-.22	-.27	-.22	-.27
Marking	-.35*	-.37*	.17	-.77
Negation	-.06	-.14	-.21	-.45*
Location	-.10	-.31	.36	-1.00***
Noncongruence	.20	.08	.23	-.08

Note: Numbers of cases vary from one correlation to another.

[a]parameters significant at $p < .05$

*$p < .05$

**$p < .01$

***$p < .001$

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